

JOINT INVENTORS

**APPLICATION FOR
UNITED STATES LETTERS PATENT**

S P E C I F I C A T I O N

TO ALL WHOM IT MAY CONCERN:

**Be it known that we, William Steve Ammons, a citizen of the
United States of America, residing at 490 Dohrmann Lane, Pinole, in the County
of Contra Costa and State of California, and Károly M. Mészáros,
a citizen of Hungary, residing at 2938 Morgan Drive, San Ramon, in the County
of Contra Costa and State of California, have invented a new and useful
METHOD OF TREATING CONDITIONS ASSOCIATED WITH INTESTINAL
ISCHEMIA/REPERFUSION, of which the following is a specification.**

**METHOD OF TREATING CONDITIONS
ASSOCIATED WITH INTESTINAL ISCHEMIA/REPERFUSION**

Asst **BACKGROUND OF THE INVENTION**

The present invention relates to therapeutic uses of

- 5 bactericidal/permeability-increasing (BPI) protein products for the treatment of adverse physiological effects associated with intestinal ischemia/reperfusion.

Reperfusion of ischemic intestines is associated with profound cardiovascular and respiratory dysfunction that may lead to shock and death.

- A variety of mediators are believed to be released from the ischemic tissue that
10 could lead to cardiorespiratory collapse, including oxygen free radicals, prostanoids, and platelet activating factor.

- During ischemia, breakdown of the intestinal mucosal permeability barrier may result in translocation of endotoxin and/or bacteria from the intestinal lumen. Endotoxin has been detected in the portal vein after
15 intestinal ischemia/reperfusion. However, a role for translocated bacteria or endotoxin in intestinal ischemia/reperfusion injury has not been clearly defined.

- Bactericidal/permeability-increasing protein (BPI) is a protein isolated from the granules of mammalian PMNs, which are blood cells
20 essential in the defense against invading microorganisms. Human BPI protein has been isolated from polymorphonuclear neutrophils by acid extraction combined with either ion exchange chromatography [Elsbach, *J. Biol. Chem.*, 254:11000 (1979)] or *E. coli* affinity chromatography [Weiss, et al., *Blood*, 69:652 (1987)] referred to herein as natural BPI and has potent bactericidal
25 activity against a broad spectrum of gram-negative bacteria. The molecular weight of human BPI is approximately 55,000 daltons (55 kD). The amino acid sequence of the entire human BPI protein, as well as the DNA encoding the protein, have been elucidated in Figure 1 of Gray et al., *J. Biol. Chem.*, 264:9505 (1989), incorporated herein by reference.

- 30 The bactericidal effect of BPI has been shown to be highly specific to sensitive gram-negative species, while non-toxic for other

microorganisms and for eukaryotic cells. The precise mechanism by which BPI kills bacteria is as yet unknown, but it is known that BPI must first attach to the surface of susceptible gram-negative bacteria. This initial binding of BPI to the bacteria involves electrostatic interactions between the basic BPI protein and the negatively charged sites on lipopolysaccharides (LPS). LPS has been referred to as "endotoxin" because of the potent inflammatory response that it stimulates. LPS induces the release of mediators by host inflammatory cells which may ultimately result in irreversible endotoxic shock. BPI binds to Lipid A, the most toxic and most biologically active component of LPS.

In susceptible bacteria, BPI binding is thought to disrupt LPS structure, leading to activation of bacterial enzymes that degrade phospholipids and peptidoglycans, altering the permeability of the cell's outer membrane, and ultimately causing cell death by an as yet unknown mechanism. BPI is also capable of neutralizing the endotoxic properties of LPS to which it binds. Because of its gram-negative bactericidal properties and its ability to neutralize LPS, BPI can be utilized for the treatment of mammals suffering from diseases caused by gram-negative bacteria, such as bacteremia or sepsis. Bahrami et al., *Int'l Endotoxin Soc. Meeting*, Vienna, Austria (August 1992), disclose the use of a BPI protein for the treatment of hemorrhagic shock.

A proteolytic fragment corresponding to the N-terminal portion of human BPI holoprotein possesses the antibacterial efficacy of the naturally-derived 55 kD human holoprotein. In contrast to the N-terminal portion, the C-terminal region of the isolated human BPI protein displays only slightly detectable anti-bacterial activity. Ooi, et al., *J. Exp. Med.*, 174:649 (1991). A BPI N-terminal fragment, comprising approximately the first 199 amino acid residues of the human BPI holoprotein and referred to as "rBPI₂₃", has been produced by recombinant means as a 23 kD protein. Gazzano-Santoro et al., *Infect. Immun.* 60:4754-4761 (1992).

SUMMARY OF THE INVENTION

The present invention provides novel methods for the treatment of adverse physiological effects associated with intestinal ischemia/reperfusion comprising administering BPI protein products to a subject suffering from the effects of intestinal ischemia/reperfusion. Specifically, the invention provides methods of treating the adverse physiological effects, including cardiac and hemodynamic effects, of intestinal ischemia/reperfusion resulting from a variety of causes. Such causes include mesenteric artery ischemia which is secondary to occlusions resulting from atherosclerosis, embolisms or arterial spasms; ischemia resulting from vessel occlusions in other segments of the bowel; ischemic colitis and intestinal torsion such as occurs in infants and particularly in animals. In particular, the invention provides methods for treating the adverse cardiac and other effects of intestinal ischemia and reperfusion associated with myocardial infarction.

The invention thus provides methods for treatment of sepsis-like conditions associated with intestinal ischemia/reperfusion comprising administering to a subject an amount of a BPI protein product effective to alleviate adverse physiological effects resulting from the presence of bacteria, bacterial particulates and endotoxin present in the body and in circulation in the blood.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 depicts the hemodynamic effects of intestinal reperfusion;
Fig. 2 depicts the effects of a BPI protein product on reperfusion-induced hemodynamic dysfunction;

Figs. 3a and 3b depict the effects of a BPI protein product on hypotension resulting from intestinal ischemia/reperfusion;

Figs. 4a and 4b depict the effects of a BPI protein product on bradycardia resulting from intestinal ischemia/reperfusion;

Fig. 5 depicts the effects of a BPI protein product on respiratory depression resulting from intestinal ischemia/reperfusion;

Fig. 6 depicts the effects of a BPI protein product on arrhythmias resulting from intestinal ischemia/reperfusion;

Fig. 7 depicts the effects of a BPI protein product on the survival time for rats subjected to intestinal ischemia/reperfusion; and

Figs. 8a and 8b depict the quantity of bacteria isolated from tissues of rats subjected to intestinal ischemia/reperfusion and the number of rats in which the bacteria were detected.

DETAILED DESCRIPTION OF THE INVENTION

The invention provides methods of treatment of the adverse effects of intestinal ischemia/reperfusion by administering BPI protein products to subjects suffering from the effects of intestinal ischemia and reperfusion. According to one aspect of the invention, the adverse cardiac and hemodynamic effects including cardiac depression, arrhythmia and hypotension associated with intestinal ischemia/reperfusion are alleviated by administration of effective amounts of BPI protein products. In particular, because these studies demonstrate the adverse cardiac and hemodynamic effects of intestinal ischemia/reperfusion, the administration of BPI protein products as an adjunctive therapy for the treatment of myocardial infarction would be particularly useful. The BPI protein products are preferably administered systemically such as intravenously, or by intramuscular or subcutaneous injection.

As used herein, "BPI protein product" includes naturally and recombinantly produced bactericidal/permeability-increasing protein; natural, synthetic, and recombinant biologically active polypeptide fragments of bactericidal/permeability-increasing protein; and biologically active polypeptide analogs or variants including hybrid fusion proteins, of either bactericidal/permeability-increasing protein or biologically active fragments thereof. The BPI protein products including biologically active fragments of BPI holoprotein which are to be administered according to the methods of this invention may be generated and/or isolated by any means known in the art.

U.S. Patent No. 5,198,541, the disclosure of which is hereby incorporated by reference, discloses recombinant genes encoding and methods for expression of BPI proteins. Co-owned, copending U.S. Patent Application Ser. No. 07/885,501 and a continuation-in-part thereof, U.S. Patent Application Ser.

- 5 No. 08/072,063 filed May 19, 1993, which are hereby incorporated by reference, disclose novel methods for the purification of recombinant BPI protein products expressed in and secreted from genetically transformed mammalian host cells in culture, and discloses how one may produce large quantities of recombinant BPI products suitable for incorporation into stable,
10 homogeneous pharmaceutical preparations.

- Biologically active fragments of BPI include biologically active molecules that contain the same amino acid sequence as a BPI holoprotein, except that the molecule lacks amino-terminal amino acids, internal amino acids, and/or carboxy-terminal amino acids of the holoprotein. Amino-
15 terminal fragments of BPI comprising up to about the first 200 amino acid residues of BPI are contemplated as being particularly useful according to the invention. By way of nonlimiting examples, such fragments include those described herein and a natural 25 Kd fragment and a recombinant 23 Kd, 199 amino acid residue amino-terminal fragment of the human BPI holoprotein referred to as rBPI₂₃. See, Gazzano-Santoro et al., *Infect. Immun.* 60:4754-
20 4761 (1992). In that publication, an expression vector was used as a source of DNA encoding a recombinant expression product (rBPI₂₃) having the 31-residue signal sequence and the first 199 amino acids of the N-terminus of the mature human BPI, as set out in SEQ ID NOS: 1 and 2 taken from Gray et al., *supra*, except that valine at position 151 is specified by GTG rather than
25 GTC and residue 185 is glutamic acid (specified by GAG) rather than lysine (specified by AAG). Recombinant holoprotein referred to herein as rBPI has also been produced having the sequence set out in SEQ ID NOS: 1 and 2 taken from Gray et al., *supra*, with the exceptions noted for rBPI₂₃.

- 30 Biologically active analogs and variants of BPI include, but are not limited to, recombinant hybrid fusion proteins comprising BPI holoprotein

or biologically active fragment thereof, and at least a portion of at least one other polypeptide. Such proteins are described by Theofan et al. in co-owned, copending U.S. Patent Application Serial No. 07/885,911, and a continuation-in-part application thereof U.S. Patent Application Serial No. 08/064693 filed May 19, 1993, which are incorporated herein by reference in their entirety and include hybrid fusion proteins comprising, at the amino terminal end, a BPI protein or a biologically active fragment thereof and, at the carboxy terminal end, at least one constant domain of an immunoglobulin heavy chain or allelic variant thereof.

Biologically active analogs and variants of BPI also include, but are not limited to, BPI protein products wherein one or more amino acid residues have been replaced by a different amino acid. For example, co-owned, copending U.S. Patent Application Ser. No. 08/013,801 (Theofan et al., "Stable Bactericidal/Permeability-Increasing Protein Products and Pharmaceutical Compositions Containing the Same," filed February 2, 1993) which is incorporated herein by reference, discloses polypeptide analogs of BPI and BPI fragments wherein a cysteine residue at position 132 or at position 135 is replaced by a different amino acid. A preferred BPI protein product described by this application comprises the first 199 amino acids of BPI holoprotein but wherein the cysteine at residue number 132 is substituted with alanine and is designated rBPI₁Δcys.

The administration of BPI protein products is preferably accomplished with a pharmaceutical composition comprising a BPI protein product and a pharmaceutically acceptable diluent, adjuvant, or carrier. The BPI protein product composition may be administered without or in conjunction with known surfactants, other chemotherapeutic agents or additional known antibiotics. A preferred pharmaceutical composition containing BPI protein products comprises BPI at a concentration of about 1 to 2 mg/ml in citrate buffered saline (0.02 M citrate, 0.15 M NaCl, pH 5.0) comprising 0.1% by weight of poloxamer 188 (Pluronic F-68, BASF Wyandotte, Parsippany, NJ) and 0.002% by weight of polysorbate 80 (Tween

80, ICI Americas Inc., Wilmington, DE). Such preferred combinations are described in co-owned, copending, U.S. Patent Application Ser. No. 08/190,869 filed February 2, 1994 which is a continuation in part of U.S. Patent Application Ser. No. 08/012,360 (McGregor et al., "Improved Pharmaceutical Composition" filed February 2, 1993), the disclosures of which are incorporated herein by reference.

Other BPI protein products useful according to the methods of the invention are BPI peptides such as those described in co-owned and copending U.S. Patent Application Ser. No. 08/209,762 filed March 11, 1994 which is a continuation-in-part of U.S. Patent Application Ser. No. 08/183,222 filed January 14, 1994 which is a continuation-in-part of U.S. Patent Application Ser. No. 08/093,202 filed July 15, 1993 which is a continuation in part of U.S. Patent Application Ser. No. 08/030,644 filed March 12, 1993 the disclosures of which are hereby incorporated by reference.

Practice of the methods of the present invention is illustrated in the following examples wherein: Example 1 discloses the effect of administration of a BPI protein product on blood pressure, heart rate and respiratory rate of rats subjected to intestinal ischemia/reperfusion. Example 2 discloses the effect of administration of a BPI protein product on the translocation of bacteria in rats subjected to intestinal ischemia/reperfusion.

EXAMPLE 1

A rat surgical model was used to evaluate the effects of BPI protein products on the physiological effects associated with intestinal ischemia/reperfusion. Specifically Sprague Dawley rats were anesthetized with a mixture of 80 mg/kg of ketamine and 4 mg/kg of xylazine administered by intraperitoneal injection. After a surgical plane of anesthesia was obtained, a tracheotomy was performed and a tracheal cannula was inserted. The animals breathed on their own. A catheter, made of polyethylene tubing, was placed in a femoral artery. The catheter was connected to a pressure transducer in

order to measure blood pressure. Another catheter was placed in a femoral vein and connected to an infusion pump.

The abdominal contents were then exposed via a midline abdominal incision. The superior mesenteric artery (SMA) was visualized at its junction with the abdominal aorta and a silk ligature was threaded around the SMA after it had been gently loosened from the surrounding connective tissue. The loose ends of the ligature were placed outside the animal and the abdominal incision was then closed with surgical staples.

After surgery, the cardiac indices of blood pressure and heart rate were electronically recorded by measurement at the femoral artery and respiration rate was determined by visual observation for a period of about 30 to 45 minutes so that all recorded variables were stable. The ligature around the SMA was then tightened by until the SMA was occluded. The SMA remained occluded for 90 minutes at which time the ligature was loosened to allow reperfusion. Sixty minutes after the SMA was occluded 7 rats received an intravenous bolus injection of rBPI₂₁Δcys in a vehicle comprising citrate buffered saline (0.02 M citrate, 0.15 M NaCl, pH 5.0) comprising 0.1% by weight of poloxamer 188 and 0.002% by weight of polysorbate 80 followed by a constant infusion of 2 mg/kg/hr. Seven other control rats received equal volumes of vehicle. The infusions continued until death.

Typical blood pressure and heart rate records for individual untreated and BPI treated rats are presented in Figs. 1 and 2 respectively. Opening the SMA occlusion after 90 minutes resulted in rapid declines in blood pressure and heart rate of all rats treated with vehicle. Within a few minutes, the heart rate of all but one control rat began to oscillate, partially in-phase with respiration, but also in a slower, more irregular pattern. In 5 of the 7 control rats there appeared to be missed beats which are presumably the result of arrhythmias. In contrast, irregularities of heart rate and arrhythmias were seldom observed in rBPI₂₁Δcys treated rats. Administration of rBPI₂₁Δcys did have an effect in reducing the hypotension resulting from intestinal ischemia/reperfusion as shown by the results in Figs. 3a and 3b

where Fig 3a shows the results for both the ischemic and reperfusion phases of the experiment and Fig. 3b shows only the period of reperfusion. Data are shown for the first 30 minutes after opening the occlusion because all vehicle-treated rats were dead within 45 minutes and all BPI treated rats were dead within 60 minutes.

The results illustrated in Figs. 4a and 4b (where Fig 4a shows the results for both the ischemic and reperfusion phases of the experiment and Fig. 4b shows only the period of reperfusion) show that the administration of rBPI₂₁Δcys had the effect of preventing bradycardia resulting from intestinal ischemia/reperfusion.

The results illustrated in Fig. 5 measuring respiratory rate show that the administration of the BPI protein product reduces respiratory depression resulting from the intestinal ischemia/reperfusion injury. The figure only presents data following reperfusion because the respiration rates for vehicle and BPI treated rats were not different prior to opening the occlusion.

The effect of intestinal ischemia and reperfusion on rats treated and untreated with the BPI protein product are set out in Table I below which illustrates the data of Figs. 3a, 3b, 4a, 4b and 5 where t=0 is immediately before reperfusion and t=30 is after 30 minutes of reperfusion.

The results illustrated in Fig. 6 relating to arrhythmia duration show that administration of the BPI protein product reduces the duration of heart rate irregularities resulting from intestinal reperfusion. For this analysis the period of time during which obvious heart rate oscillations or arrhythmias were observed was determined for each rat and then averaged. The results were statistically significant with $p < 0.001$.

The results illustrated in Fig. 7 show that treatment with the BPI protein product increases survival time in rats suffering from intestinal ischemia/reperfusion injury ($p < 0.05$). According to this aspect of the experiment, the time from opening the occlusion until death was recorded for each rat. In all cases death was immediately preceded by a rapid decline in respiration rate and reduction in tidal volume.

TABLE I

	Blood Pressure (mmHg)		Heat Rate (per min.)		Respiratory Rate (per min.)	
	t = 0	t = 30	t = 0	t = 30	t = 0	t = 30
Vehicle	96 \pm 5	37 \pm 3	288 \pm 2	241 \pm 16	51 \pm 3	29 \pm 3
rBPI ₂₁ Δcys	96 \pm 5	43 \pm 5	284 \pm 7	325 \pm 9**	56 \pm 4	40 \pm 4*

t = 0 is immediately before reperfusion, t = 30 is 30 minutes of reperfusion.

* p < 0.05 vs. Vehicle, ** p < 0.01.

EXAMPLE 2

In an additional experiment with the rat surgical model of experiment 1 two groups of five rats each were surgically prepared and administered with either rBPI₂₁Δcys, or vehicle in the same manner and dosages as in example 1 except that a blood sample was obtained just prior to death. In addition a third group of five rats was subjected to a sham operation wherein all the surgical procedures were reproduced with the exception that the SMA was never occluded. After death, samples of tissue were obtained from the liver, spleen, and mesenteric lymph nodes. The blood was plated on trypticase soy agar and incubated overnight at 37°C. The tissue samples were then weighed and homogenized and were similarly plated and incubated overnight at 37°C. The next day the number of colonies on the plates were counted visually. The number of bacteria per gram of tissue of each organ is shown in Fig. 8a. The number of rats in which bacteria were detected is shown in Fig. 8b. These results including the sham experiment show that intestinal ischemia/reperfusion results in translocation of bacteria, most likely from the gut. Further, the results show that the administration of the BPI protein product reduced the translocation of bacteria resulting from intestinal ischemia/reperfusion. Analysis of the blood samples indicated no presence of bacteremia in any of the subject animals.

Numerous modifications and variations in the practice of the invention are expected to occur to those skilled in the art upon consideration of the foregoing description of the presently preferred embodiments thereof. Consequently, the only limitations which should be placed upon the scope of the present invention are those which appear in the appended claims.